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Evaluating the Impact of Elevated Temperature on *Melia dubia*: Insights into Climate Change Resilience and Adaptation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The consequences of climate change extended beyond temperature shifts, encompassing more extreme weather events, increased carbon di oxide enabling some plants to tolerate environmental stresses, and shifts in precipitation patterns,. Climate change manifests through alterations in the mean and variability of various properties, persisting for extended periods, often decades or longer, either due to natural variability or human-induced factors. The increase in green house gas emissions results from fossil fuel energy production, industrial activities, transportation, agriculture, construction, deforestation, and land-use changes. Plant height plays a pivotal role in the growth and development of plant species. Elevated temperature levels have been observed to enhance plant productivity, with variying impacts based on the growth stage and species response to the environment, independent of climate changes. *Melia dubia* is an economically important tree species grown throughout the world and the morphological, physiological and biochemical characteristics to variying air temperature is discussed in this paper

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1. INTRODUCTION

Global warming is a primary driver of climate change, largely attributed to the escalating levels of atmospheric carbon dioxide (CO_2) and other greenhouse gases (GHGs) like methane (CH_4), nitrous oxide (N_2O), and Chloro Fluoro Carbons (CFCs) over the past two decades. These GHGs trap long-wave radiation emitted by the Earth's surface, leading to atmospheric warming. Climate change manifests through alterations in the mean and variability of various properties, persisting for extended periods, often decades or longer, either due to natural variability or human-induced factors. The bulk of GHG emissions results from fossil fuel energy production, industrial activities, transportation, agriculture, construction, deforestation, and land-use changes. Natural events such as forest fires and volcanic eruptions also contribute to increased GHG levels. The Intergovernmental Panel on Climate Change (IPCC), established in 1988 by the United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO), plays a pivotal role in assessing climate change and advocating for GHG emission control. The IPCC's fifth assessment report (AR5) in 2013-14 unequivocally asserted that global warming is occurring, associated with heightened GHG concentrations in the atmosphere. Recent studies emphasize the urgency of peaking GHG emissions before 2020 to curb the average global temperature increase to 2°C above pre-industrial levels. Rising temperatures pose significant challenges, with a global mean surface temperature increase of 0.85°C from 1880 to 2012. Predictions suggest a potential rise of 0.3-4.8°C by the end of this century, with higher increases in certain regions like northern Europe [53]. Elevated temperatures have profound implications for agriculture, potentially causing a decline in food production. Heat stress affects plant growth, development, and crop yield, particularly in tropical regions. The IPCC warns of a 15-25% decline in food production in southern India and 25-50% in northern parts. In response to these challenges, understanding the impact of elevated temperatures on plant species is crucial. The global agricultural landscape faces a daunting task of addressing poverty and hunger amidst the escalating challenges posed by climate change. With projections indicating a need for a 70 percent increase in food production to feed an additional 2.3 billion people by 2050, the focus on enhancing food productivity becomes paramount. This urgency is particularly emphasized in the context of leguminous pulses, crucial for their economic importance, rich nutritional content, and diverse applications in human consumption, livestock feed, and industrial processes. Temperature stress imposes challenges in plants at various organizational levels with deleterious effects on vegetative and reproductive growth [55]. An increase of 0.2ºC in the average temperature has been predicted to occur over the next decade [54]. One of the primary threats to global food supply production is the rise in average air temperature, predicted to increase by 0.3-0.7ºC by 2035 and potentially reaching 1.8 – 4.0ºC higher temperatures than the current level by 2100. Elevated temperature is emerging as a significant seasonal phenomenon and a component of climate change, presenting a formidable challenge to plant life. Understanding the mechanisms of heat stress in plants is imperative for future generations, given the potential repercussions on food production.

2. CLIMATE CHANGE DYNAMICS

Climate change, defined as a long-term alteration in the statistical distribution of weather patterns over periods ranging from decades to millions of years, manifests in various forms. The indicators of climate change include rising temperatures over oceans, tropospheric temperature changes, alterations in temperature over land, sea surface temperature fluctuations, changes in humidity, sea level variations, and shifts in ocean heat content. Conversely, indicators expected to decrease include sea ice, snow cover, and glaciers. Global warming, a focal point of concern, is closely linked to the surge in greenhouse gas (GHGs) emissions. Concentrations of gases such as CO_2, CH_4, and N_2O have unprecedentedly increased by 40 percent, 150 percent, and 20 percent, respectively, since 1750. Projections indicate a potential increase in global mean surface temperatures by 1.4 to over 5ºC by 2100. The consequences of climate change extend beyond temperature shifts, encompassing more extreme weather events, increased CO_2 enabling some plants to tolerate environmental stresses, and shifts in precipitation patterns. First report on global warming was brought out which stated that earth has warmed up in the past century, low at the beginning of 20th century and more intense in the past few decades. The global warming event is closely related to the rise in greenhouse gas (GHGs) emissions and these gas concentrations such as CO_2, CH4 and N_2O increased unprecedentedly to 40 per cent, 150 per cent and 20 per cent respectively since 1750 [10]. Increase in global average temperatures would further result in drastic shifts in the annual precipitation with a 20 per cent reduction per year and about 20 per cent loss in soil moisture [49]. As a consequence of climate change, plants may be more often subjected to high temperatures and low soil moisture during the growing season in spring and summer [29]**.**

3. IMPACT OF ELEVATED TEMPERATURE ON CROPS

Elevated temperature stress, characterized by temperatures surpassing a threshold level for a duration sufficient to cause irreversible damage to plant growth and development, has profound implications for agriculture. The effects vary between C_3 and C_4 plants, with C_3 plants generally experiencing negative impacts on growth. While rising temperatures benefit C_4 plants' photosynthesis, the stimulating effects of CO_2 on C_3 plants can be overridden. Understanding the complexity of temperature stress involves considering factors such as intensity, duration, and the rate of temperature change. High temperatures influence various physiological processes, including growth, development, and yield in crops. For instance, temperature stress before flowering can lead to reduced germination percentage, increased abnormal seedlings, early flowering, nodules degeneration affecting nitrogen fixation efficiency, and impacts on photosynthetic activity and plant biomass. As the global community grapples with the multifaceted challenges of climate change, research and concerted efforts are essential to develop sustainable agricultural practices. Insights into the impact of elevated temperatures on crop production are crucial for adapting agricultural systems to ensure food security in the face of changing climate dynamics.

Negative effect of higher temperatures on C3 plants depends on the norm of reaction of the plant species and the prevailing environmental conditions. High temperature stress is known to influence plant growth and development and various physiological and yield processes. [27] also stated that temperature is most influential factor, which affects the plants chemically, physiologically and biologically. The impact of temperature stress is a complex function of intensity, duration, and rate of temperature change. The extent to which it occurs in specific climatic zone depends on the probability and period of high temperature occurring during the day or the night [57].

4. MORPHOLOGICAL RESPONSES IN ELEVATED TEMPERATURE

4.1 Shoot Responses

Plant height plays a pivotal role in the growth and development of plant species. Elevated temperature levels have been observed to enhance plant productivity, with varying impacts based on the growth stage and species response to the environment, independent of climate changes. Studies by [42] suggest that faster-growing species exhibit more significant growth increases in response to elevated temperatures, with growth rates potentially rising by 10 percent across various species.

4.2 Root Responses

Elevated temperature levels contribute to alterations in developmental processes, including root and shoot architecture. Research by [46] indicates an increase in root dry weight in tree species under elevated temperature conditions. Additionally, studies on Scots pine seedlings revealed substantial increases in total root length and total root dry mass, emphasizing the influence of elevated temperatures on root development [26]. Other species, such as *Plantago lanceolata*, have demonstrated notable increases in both shoot and root dry matter production under elevated temperature conditions [23].

4.3 Leaf Level Responses

Leaf area, a critical component linked to physiological processes controlling dry matter production and yield, experiences positive correlations with elevated temperature. Research by [8] suggests a positive correlation between leaf area and dry matter accumulation in pea varieties. Elevated temperature has been shown to increase the leaf area index (LAI), attributed to enhanced photosynthetic efficiency and lower light compensation points, allowing leaves to maintain a positive carbon balance [17]. Studies on populous clones indicate an 8-18 percent increase in leaf area under elevated temperature conditions [7].

4.4 Morphological Responses in Elevated Temperature

Elevated temperature influences the height, diameter, and biomass of broadleaf tree species in boreal regions until reaching the optimum temperature. Increased photosynthetic rates lead to faster growth and higher biomass production, with photosynthetic carbon gain accounting for the majority of plant biomass accumulation [2]. Genotypic characteristics also play a role in regulating the physiology and growth of trees [31,4].

4.5 Growth Increment

Higher temperatures have been linked to increased cell division, resulting in heightened plant height. This aligns with studies by [60], reporting an increase in the height of oak seedlings under elevated temperatures compared to ambient conditions.

4.6 Leaf Area

Photosynthesis and morphogenetic processes are susceptible to higher temperatures, causing modifications in plant growth. Elevated air temperatures initially improve leaf extension but accelerate maturity, limiting final leaf size [45]. The effects of radiation on photosynthetic activity and leaf area have been reported, with increased air temperatures improving leaf extension [36].

4.7 Collar Diameter and Number of Leaves

Increased air temperature synergistically influences plant growth, improving collar diameter, the number of leaves, and leaflets. These findings align with the work of [44].

5. PHYSIOLOGICAL RESPONSES IN ELEVATED TEMPERATURE

5.1 Photosynthetic Rate

Photosynthesis is significantly impacted by elevated temperatures, with reductions observed at higher temperatures. The PS II system is particularly affected, leading to chlorophyll degradation and inhibition of Rubisco, ultimately causing yield reduction [12]. Elevated temperature stress can influence photosynthesis through stomatal closure and decreased CO_2 flow [20].

5.2 Transpiration Rate

Transpiration rates increase under high temperatures due to stomatal opening. The balance between low photosynthetic rates and high transpiration rates during temperature stress affects plant establishment, particularly in crops like chickpea [51]. Adequate water supply is essential for coping with high-temperature stress, as transpiration cooling plays a crucial role [59].

5.3 Stomatal Conductance

Stomatal conductance and net photosynthesis are hindered by elevated temperature stress, primarily due to decreased Rubisco activase enzyme. Studies on tobacco plants under stress have shown stomatal conductance increases up to 40 percent between 30 and 40ºC but declines above 40ºC [30]. Elevated temperature stress during flowering in soybean has been observed to decrease stomatal conductance [15]. In summary, the intricate interactions between elevated temperature and plant responses involve complex morphological and physiological changes. Understanding these responses is crucial for predicting and mitigating the impacts of climate change on plant growth and productivity.

5.4 Leaf Temperature

Leaf temperature is a crucial parameter affected by high-temperature stress in plants. Changes in transpiration rate can lead to alterations in leaf temperature [16]. Stomatal closure results in the termination of evapotranspiration, causing an increase in leaf temperature [33]. Environmental factors and transpirational cooling significantly influence the surface temperature of plant leaves [38,50]. Elevated leaf temperature under stress inhibits enzymatic activity and various physiological processes, ultimately deactivating photosynthetic mechanisms [9,12].

5.5 Water Use Efficiency (WUE)

Water use efficiency (WUE), defined as the ratio of water loss to carbon fixed during photosynthesis, is a critical leaf-level response to elevated temperatures. While an increase in WUE is common, it may not necessarily be directly proportional to changes in plant growth and photosynthesis [5]. Elevated temperature, coupled with reduced stomatal opening, conductance, and transpiration rates, also depresses dark respiration rates, leading to enhanced WUE [62,37]. The rise in WUE is associated with increased drought tolerance in many plants, potentially allowing for expanded plant distributions [56,24]. However, not all C4 crop plants exhibit a positive response to elevated growth temperature. Numerous single-species studies on various trees, including longleaf pine, red oak, scrub oak, silver birch, beech, sweet gum, and spruce, document positive responses in WUE to elevated atmospheric temperature concentrations [63]. Intrinsic water use efficiency (IWUE), which considers the ratio of photosynthetic CO_2 uptake to transpirational water vapor loss, is crucial for evaluating the response of different tree species to elevated temperature. Studies on *Quercus robur, Fagus sylvatica,* and *Pinus sylvestris* trees show significant increases in IWUE under elevated temperature concentrations [58]. Similar findings in *Sabina przewalskii* and *Picea crassifolia* trees indicate a long-term increase in IWUE, contributing to a better understanding of how different tree species respond to elevated temperature conditions in specific environments [32].

6. BIOCHEMICAL RESPONSES IN ELEVATED TEMPERATURE CONDITIONS

6.1 Chlorophyll

Chlorophyll, a critical pigment for photosynthetic capacity, serves as a sensitive indicator of environmental conditions. Chlorophyll a and b are essential for converting light energy into stored chemical energy. Chlorophyll content directly influences photosynthetic potential and primary production [13]. Leaf chlorophyll content provides an indirect estimation of nutrient status, as a significant portion of leaf nitrogen is incorporated into chlorophyll [18]. While some studies, such as those by [62], observed a reduction in chlorophyll and accessory pigments in response to elevated CO_2 and temperature, other research demonstrates that atmospheric CO_2 enrichment may increase, decrease, or have no effect on leaf chlorophyll concentrations.

6.2 Nitrogen Use Efficiency

Elevated temperature environments increase the nitrogen demands of plants due to accelerated growth and metabolism. This increased demand for nutrients, particularly nitrogen, is essential for various growth processes. Studies by [34] indicate that elevated temperature leads to increased nitrogen demands, resulting in greater total biomass compared to ambient levels. Other studies, such as those on strawberry and *Trifolium repens,* suggest that elevated temperature levels enhance growth-based nitrogen use efficiencies [35].

6.3 Total Carbohydrates

Greater carbohydrate supply and improved water use efficiency contribute to larger individual leaves and more rapid canopy development under elevated temperature conditions. Increased photosynthetic activity and water use efficiency lead to enhanced carbohydrate content in tree species [17]. While initial enhancements in photosynthesis rates may occur in C_3 plants exposed to elevated temperature, acclimation to the environment often leads to a subsequent decline [6]. In conclusion, the biochemical responses of plants to elevated temperature conditions involve intricate interactions, influencing crucial parameters such as chlorophyll content, nitrogen use efficiency, and carbohydrate levels. Understanding these biochemical responses is essential for predicting the impact of climate change on plant physiology and productivity.

6.4 Proteins

The impact of elevated temperature on protein concentration in plants has been a subject of study, and contrasting results have been reported [48] observed a temperature-induced reduction in the protein concentration of flour derived from wheat plants. Similarly, [3] reported lower nitrogen concentrations but higher water-soluble carbohydrate concentrations in leaves of individual species under enriched temperature levels. [41] also observed an increase in protein concentration in response to elevated temperature, despite a reduction in overall protein concentration. Contradictory findings were reported by [28], who observed a 50% increase in leaf protein concentration under enriched temperature levels in wheat plants. The studies conducted by [25] reported varying effects on protein concentration under elevated temperature levels across different agricultural crops.

6.5 Phenol Components

The presence of phenolic compounds in plants plays a crucial role in their response to elevated temperatures. [61] observed a significant increase (40.6%) in total phenolic content in cattails grown in elevated temperature levels compared to ambient air. [19] reported a notable increase in both above and below-ground total phenolic concentrations in loblolly pine seedlings grown in elevated temperature conditions. Similar findings were observed in temperate regions by [40], who reported a 20 to 605 increase in leaf phenolic concentrations in response to a doubling of CO_2 content. Additionally, [61] observed a 63.2% increase in total phenol compounds in aspen seedlings grown in elevated temperatures. [11] studied nine species of tropical trees, with eight species exhibiting positive leaf phenolic responses, and one species showing a 27% decline. The mean response of all nine species was an increase of 48% in phenol content. These results indicate that both temperate and tropical trees show large interspecific variation in their response to temperature, with an average increase in phenol content of 50%. In contrast, [22] found no significant effect of elevated temperature on the chemical composition of leaves in loblolly pine plantations. Similarly, [21] detected no significant difference in total phenolic content in three oak species between high-temperature and ambient treatments.

6.6 Future Temperature Projection

Asia has experienced increasing surface air temperatures, with more pronounced changes during winter than summer. The observed increase ranges from less than 1°C to 3°C per century across different sub-regions. Climate change is recognized as a major threat, impacting ecosystems, agriculture, water resources, and socio-economy globally and regionally. The linear warming trend over the last century was 0.74°C, nearly twice that of the previous 50 years. Projections based on various emission scenarios indicate a temperature increase of about 3 to 5°C by 2070 over the Indian region. Specific predictions for Tamil Nadu and the Upper Ganga Basin also indicate substantial temperature increases.

The temperature was projected to increase more in the areas which were warmer at present and relatively lesser in the hilly areas of Dehradun, Haridwar and Bijnor [1]. The increase in surface temperature was most pronounced in North Asia [47].

6.7 Growth Chamber Studies and Design

Several studies have employed growth chambers to simulate elevated temperature conditions. [14] used a temperature-controlled study for sorghum, while [43] conducted an experimental trial on rice crops using a Climate Control Chamber. [64] designed temperature-controlled chambers for field experiments, monitoring air temperature and relative humidity. [52] employed Open Top Chambers (OTCs) made of aluminum frames covered with UV-treated polycarbonate sheets for a field experiment on sorghum. [39] studied varietal differences in black gram under elevated temperatures using open-top chambers made of polycarbonate sheets with steel tubes as frames. These growth chamber studies and experimental designs provide valuable insights into the response of various crops to elevated temperatures, facilitating our understanding of climate change impacts on agriculture and forestry.

7. CONCLUSION

In conclusion, the global agricultural landscape is confronted with the daunting challenge of addressing poverty and hunger, especially given the anticipated 70 percent increase in food production needed to feed an additional 2.3 billion people by 2050. The urgency to enhance food productivity is particularly critical for leguminous pulses, which hold economic importance and provide rich nutritional content with diverse applications. One of the primary threats to global food supply is the rise in average air temperature, predicted to escalate significantly in the coming decades. Elevated temperature is emerging as a significant component of climate change, posing a formidable challenge to plant life and, consequently, food production. Understanding the mechanisms of heat stress in plants is crucial to navigate the potential repercussions on agricultural systems and food security. The dynamics of climate change manifest through various indicators, including rising temperatures, alterations in humidity, sea level variations, and shifts in precipitation patterns. Global warming, primarily driven by increased greenhouse gas emissions, poses multifaceted challenges, including extreme weather events and changes in plant responses. Elevated temperature stress has profound implications for agriculture, impacting various physiological processes in crops. Morphological responses, such as shoot, root, and leaf-level changes, vary among different plant species. Understanding these responses involves considering factors like intensity, duration, and the rate of temperature change. Physiological responses to elevated temperature encompass parameters like photosynthetic rate, transpiration rate, stomatal conductance, and water use efficiency. These responses play a critical role in determining plant growth, development, and overall productivity. Biochemical responses in elevated temperature conditions involve changes in chlorophyll content, nitrogen use efficiency, and carbohydrate levels. These responses are intricate and crucial for predicting the impact of climate change on plant physiology. The review also emphasizes the importance of growth chamber studies and experimental designs to simulate elevated temperature conditions, providing valuable insights into crop responses. These studies contribute to a better understanding of climate change impacts on agriculture, aiding in the development of sustainable practices. Looking forward, the response of tree species to elevated temperature emerges as a critical area of research. Understanding the adaptive genotypes and responses of various tree species, particularly in tropical regions, will be essential for developing resilient ecosystems in the face of changing climate dynamics. In summary, as the world faces the challenges of climate change and the need for increased food production, research, and concerted efforts are crucial. Insights into plant responses to elevated temperatures are imperative for developing adaptive strategies to ensure food security and sustainable agricultural practices for future generations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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